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Joint Institute for Nuclear Research

Laboratory of Nuclear Problems

Starting Up of a Cyclotron with a Wide Variation In the Magnetic Field Intensity

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In January, 1959 in the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research in Dubna, a cyclic accelerator of new design was started which has a periodic pattern of the magnetic field both azimuthally and radially. The diameter of the magnet is 1200 mm. The line of constant flux of the magnetic field is bent according to Archimedes spiral[1] $r = 16.2\varphi$ (cm), the periodicity of the magnetic field pattern being $N = 6$.

The mean value of the magnetic flux increases along the radius in accordance with the relativistic increase in the mass of the accelerated ion. As the acceleration starts at the center of the magnet, the frequency of the free oscillations vary accordingly from $Q_z = 0$, $Q_r = 1$ at $r = 0$ to $Q_z = 0.2$, $Q_r = 1.01$ at $r = 52$ cm. The operating point moves in the stable area, never crossing the line of the corresponding resonance frequencies. An exception to this is the non-linear resonance effect in the center of the magnet ($Q_r = 1$). This effect was studied in detail in 1958 on a model whose magnetic field had a periodic pattern with $N = 4$. The radial step of this pattern was $2\pi\lambda = 8.72$ cm, and the line of constant field was bent according to the spiral $r = 5.4\varphi$ cm.

It was shown theoretically that the required increase of the mean value of the magnetic flux along the radius necessary for the removal of the non-linear resonance effect in the center of the accelerator decreases with an increase in N, hence in the order of the non-linear resonance; as $\frac{N}{2^N (N-1)!}$ and with an increase of the radial step (with a fixed N) as $\left(\frac{\lambda_1}{\lambda_2}\right)^{N-2}$.

Since the development of the non-linear resonance effect at $Q_z = 1$ is

dependent on the displacement of the center of the instantaneous orbits relative to the center of the magnetic field, it was decided that studies of the conditions for vertical stability in displaced orbits should be made. As a result of these studies, it was established that in order to avoid producing changes in the character of the vertical oscillations, the displacement of the centers of the instantaneous orbits should not exceed λ. Similar requirements are necessary for small deviations of the period of particle revolution on the displaced orbit from the resonance value.

The results of these studies were put to use when choosing the parameters for the above indicated six-spiral pattern of magnetic field in which the non-linear resonance in the center of the accelerator was not observed. The necessary variation in the magnetic field was achieved with the help of iron shims of perpendicular transverse section. The configuration for optimum dimensions of the shims, which quarantee the necessary depth of variation in intensity of the magnetic field, was based on the assumption of complete magnetic saturation of the shims. The increase in the intensity of the center of the magnetic field along the radius corresponding to the necessary constancy in the revolution frequency of the ion, was accomplished with the help of thin cylindrical shims, which were considered when the assumption of uniform magnetization was made. For the removal of the influence of the simple and parametric resonance ($Q_r = 1$) a shimming of the first and second harmonic in the pattern of the magnetic field was performed with the help of symmetrically placed cylinders of small diameters (8 mm.). All the measurements of the magnetic field intensity were performed on a nuclear magnetometer to an accuracy of $\pm$ 1.5 oersted[2]. The constancy of the magnetic field (in time) was maintained

by a nuclear stabilizer[3].

For accelerating the ions, a resonant quarter wave system with one dee was used. The feeding of the resonant system was accomplished by a generator with a separate excitation, making available an accelerating voltage of up to 40 KV.

On this cyclotron, deutrons were accelerated up to 12 Mev in energy, and alpha particles up to 24 Mev with a minimum amplitude of the accelerating voltage on the dee of 8 KV. The measurement of the energies of the accelerated particles on the maximum radius of 52 cm. was performed in two ways.

a. Measurement of the center of curvature of the orbit by means of three probes.

b. Measurement of the passing of the deutrons through an aluminum foil.

All measurements were performed at beam intensities of ~1 μa, as a result of which there was no noticeable increase in activity on the interior of the chamber.

In Fig. 1 are shown autoradiographs of the beam at different radii of the accelerator. A general view of the accelerator is shown in Fig. 2. The results of the experiments performed indicate the feasability of a relativistic proton cyclotron at energies which can only be achieved at present with a synchrophasatron.

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Literature.

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Publishing Dept., Joint Institue of Nuclear Research, May, 1959.

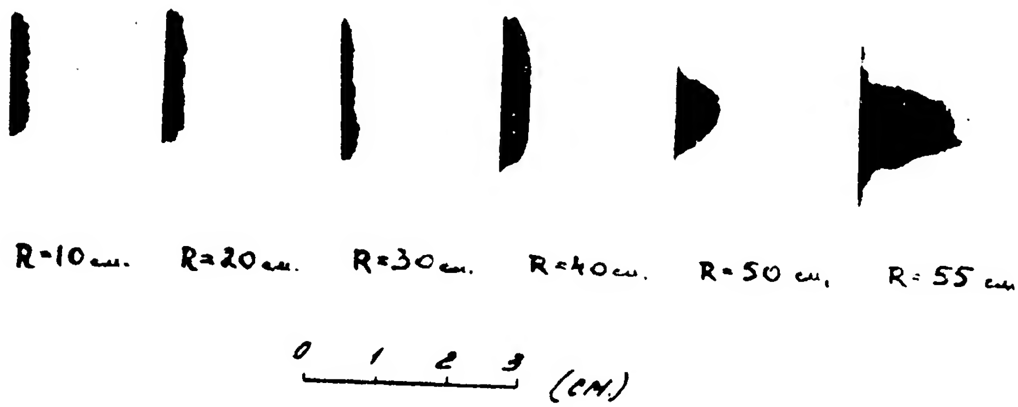

Рис. 1.

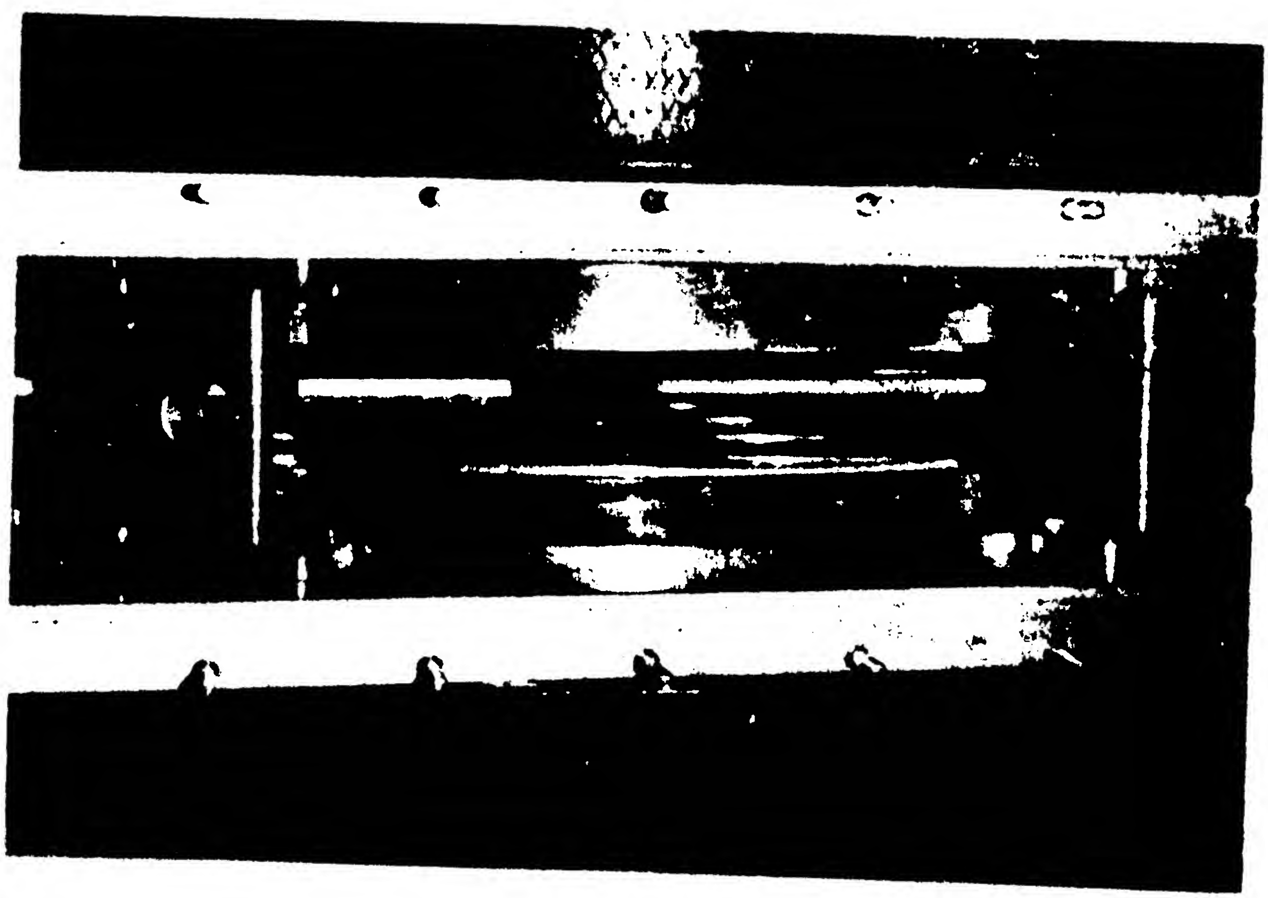

Рис. 2.